



## Corrigendum: Effect of crop maturity condition and operating factors on the threshing performance of wheat thresher

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### Abstract

Sustainable agriculture is majorly related to mechanized agriculture systems. The outdated threshing operations lead to a negative impact on wheat threshing performance and contribute to overall post-harvest losses. Mechanized agriculture could produce encouraging results for productivity enhancement including grain damage reduction, better efficiency, and improved threshing technology. The objective of this research study was to assess the effect field operating conditions in the farmers field and maturity characteristics of wheat on threshing performance of locally developed wheat thresher during wheat seasons 2017-18. The wheat thresher produced significantly higher results for wheat (Faisalabad-2008) with the mean threshing efficiency (98.83%) and grain cleaning efficiency (98.93%) at crop moisture (16.6%) and feeding of 52 kg/min. while the least grain breakage percentage (0.75%) was found. The quantity of grain lost in wheat straw was found to be minimum 0.16% at the feeding rate of 47 kg/min and mid harvesting stage (16.6%). The wheat thresher chopped straw size was (2.28 cm) accurate and uniform at moisture content 16.6% (mid harvesting stage) while the straw chopping was non-uniform and irregular at late harvesting stage of wheat crop (1.93cm). The maximum fuel consumption and energy utilized were calculated to be 6.71 L/h and 76.57 kWh respectively for wheat variety Lasani-2008 (V<sub>3</sub>) at feeding rate FR<sub>3</sub>, 52 kg/min. The results revealed that the crop moisture content and feeding rate has significant effects on threshing efficiency, cleaning efficiency and grain damage.

**Keywords:** Agriculture mechanization, Economic analysis, Operating characteristics, Threshing performance, Wheat thresher

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### Introduction

Wheat is considered the first cereal crop with optimum production (Callaway, 2014; Khan et al., 2016; Anser et al., 2018; Shafqat et al., 2019). The cultivation area for wheat was 8,734 thousand hectares during 2017-18 in Pakistan but the wheat production was 25.492 million tons. Wheat contributes 9.1% in value addition and 1.7% of GDP of Pakistan (Gobbett et al., 2017; Mehmood et al., 2020; Shehzad et al., 2022; Shafqat et al., 2023). The increasing population to 200 million has created a gap between demand and supply of food commodities (Economic Survey of Pakistan, 2018; Shaheen et al., 2023; Shehzad et al., 2023). This can be compensated for with higher crop yields, attractive output prices and supportive government policies towards sustainable agriculture system (Economic Survey of Pakistan, 2018). Wheat production faces various challenges (technology access, capital), that specify the nature of agricultural technologies and their adoptability. Therefore, farmers have the option to use either traditional

or conservation agriculture technologies for wheat threshing. The elevation of conservation agriculture requires identifying the issue of social, financial, agronomic diversity and developing location specific technologies. Agricultural technologies directly impact the dissemination of conservation agriculture-based resources conserving technologies practices (Krishna et al., 2012).

Conservation crop production and mechanized post-production processing of wheat crop play an important role for supplying staple food in sustainable agriculture. The 25 million tons of wheat lost occur at the harvesting stage and this loss has been recorded 46% in developing countries (Byerlee & Curtis, 2006). These agricultural practices that can potentially increase crop yield, minimize production cost, and facilitate sustainability of agriculture development may involve minimum grain damage, reduce grain losses, improve grain cleaning, and enhance threshing efficiency, (Krishna et al., 2012). Unlike traditional wheat threshing, the grain damage was reduced four times, and the observed threshing efficiency was 99% after this conservation threshing technology. The crop moisture at

harvesting stage and rate of feeding wheat into the threshing drum influence threshing performance which results in more losses, thereby reducing wheat yield. Therefore, suitable moisture and feed rates are required for wheat threshing (Byerlee & Curtis, 2006).

Wheat threshing is considered as an important agricultural practice in a sustainable agriculture system. Mechanizing wheat threshing activity to optimize wheat yield and time saving because the losses of mechanical threshing were 2.68% than manual threshing 3.11%. The 2.65% potential production of wheat crop lost during harvesting, threshing, and winnowing operation (Byerlee & Curtis, 2006). The modification and improvement of harvesting and threshing technologies have socio-economic benefits than simple reduction of grain loss, which will result as a natural consequence of development in sustainable agricultural sector in which post harvesting technology plays a critical role (Chaudery, 1979). Agricultural technology connects sustainability with increased crop productivity. To meet the requirement of food grain, sustainable food production is necessary which includes introducing high yielding varieties coupled with mechanized wheat threshing. Sustainable agriculture system is a fact in developing agriculture to obtain higher yield (Agha et al., 2004).

The grain breakage and grain losses in straw in wheat threshing was significantly associated with threshing method and crop condition (Kumar et al., 2017). There four principles involved in wheat threshing are rubbing of crop material, impact of threshing tool, combining, and grinding of chopped crop material (Kemanian et al., 2007; Yang et al., 2016). The thresher and harvester are the more important agricultural machineries that enhance threshing and harvesting performance respectively (Zami et al., 2015; Wu et al., 2016; Cerquitelli, 2017) but the most important function is threshing (Hanna and Quick, 2013). The wheat threshing performance of thresher like gain damage and grain loss significantly affected by contact method of threshing drum and wheat crop (Spokas et al., 2008; Alizadeh and Bagheri, 2009; Zareiforush et al., 2010; Khir et al., 2017).

Many researchers have been investigating different types of wheat threshers or threshing components since 1820s (Ndirika, 2005; Li et al., 2012; Gbabo et al., 2013; Yang et al., 2016; Wang et al., 2016) but the peak level of threshing method and machinery are not available due to the gain damage and grain loss factors. Grain loss is the key parameter for performance evaluation of grain thresher (Nawrocka et al., 2012; Abdi and Jalali, 2013; Markowski et al., 2013; Karlen et al., 2014). The grain losses were found nature, cutting & rolling, pick-up and threshing & separating (Pishgar-Komleh et al., 2013). Natural loss resulted from climatic conditions, i.e., wind and rain (Audilakshmi et al., 2007) while the rest were associated with threshing method. The only mechanical loss may reduce to optimize grain threshing. Similarly grain damage affects market value and storage (Harrison, 1992; Baryeh, 2003; Khazaei et al., 2008; Lashgari et al., 2008; Mirzazadeh et al., 2012; Behnke and

Brune, 2014). The contact between crop grain and threshing surface result gain damage due to high relative speed (Kalkan et al., 2011; Agelet et al., 2012; Shahbazi, 2012; Zhu et al., 2016). The textural features of the grain with impact force of thresher had been studied by highspeed digital imaging technique (Delwiche et al., 2013). The fungal biological damage occurred due to high moisture at harvesting stage (Delwiche et al., 2011; Singh et al., 2012). Grain crops harvested at physiological maturity reduced grain damage up to a minimum level (Herrera et al., 2015; Zhou et al., 2015; Baktash & Alkazaali, 2016). The modification of threshing component had reduced grain loss and damaged (Ahmad et al., 2013). The modification of contact condition for wheat threshing enhanced threshing efficiency from 94.8% to 99% than conventional. The seed breakage was found to be 0.3% than 0.6% which was less than seed damage in conventional method (8.4%) (Mesquita et al., 2000). The strip rotor with rubber blades instead of cutter bar system gave better threshing efficiency (Kalsirisilp & Singh, 2001). The wheat thresher performance based on performance of concave, the experiments on concave clearance and drum speeds showed that the grain breakage was low at concave clearance increased from 29mm to 35mm while it was more when drum rotates from 675 rev./min to 875 rev./min (Sudajan et al., 2005). These empirical techniques reduce grain loss and damage and are applicable in specific threshing conditions.

Evaluation of threshing performance predicts possible modification and provides guidelines towards designing more intelligent thresher for better field operations. The reliable measure of field testing is the rate at which the required agricultural machinery accomplishes intended function (Barger et al., 1972; Noor et al., 2021). The evaluation of machinery also details the deficiencies still present in the performance, durability of components and safety (Yasin and Ansari, 1981). The conservation agricultural system and the mechanized wheat threshing are optimum solutions to overcome the problem in wheat threshing that help to improve threshing performance and reduce grain losses. The main objective of this study was to design, develop and evaluate the threshing performance of a wheat thresher in conservation agriculture system under farmer's fields conditions for wheat varieties Seher 2006 (V1), Faisalabad 2008 (V2) & Lasani 2008 (V3) at early, mid & late harvesting stages (moisture content) and feeding rates (FR1, 41 kg/min, FR2, 47 kg/min & FR3, 52 kg/min) on threshing efficiency, grain cleaning efficiency, grain breakage percentage, grain loss in straw, straw chopping efficiency and fuel consumption. It was also aimed to recommend suitable operating modes under the conservation agriculture system and solve the problem against further adaptation of conservation of agricultural technology due to optimized threshing performance.

## Materials and Methods

A Wheat thresher with modification in design, fabricated with locally available materials, techniques and standards for wheat threshing under different crop and machine parameters i.e., wheat moisture content, wheat variety, feed rate, concave clearance, and speed of threshing drum. This wheat thresher was

tested and consisted of 4 units; feed and threshing, sieving, cleaning and power transmission & transportation (Fig. 1). The thresher components with their salient features and the material used were presented in Table 1.

## Description of functional units of wheat thresher

### Feeding and threshing unit

The objective of the feeding system was to feed the wheat crop into threshing unit of thresher. This unit consisted of a feed shaft and pulley (70 rev./min) from main shaft (800 rev./min) through feed pulley. The feed shaft connected with

8 feed stars was used to deliver wheat material into the threshing drum. The threshing system comprised of threshing drum, rings and 100 beaters (cutter bars) on the rings of the threshing shaft and concave. The wheat crop was fed into the clearance between rotating drum and circumference. The beaters rotating with high revolving speed stroke wheat crop and detached through impact and rubbing force (Alluvione et al., 2011; Xu et al., 2013; Liang et al., 2017). The wheat material passed through clearance between concave and beaters. The concave clearance optimized the threshing yield (Sudajan et al., 2005). That threshed grain and straw chopped moved into sieving unit through concave grates.



**Fig. 1** Wheat thresher and its functional units

### Sieving and cleaning unit

The sieving and cleaning unit consisted of Set if round hole sieves, set of blowers. In this unit grain was separated from stalks with the help of main blower connected with main threshing shaft (800 rev./min) for cleaning of grain from straw. The finer chaff was removed through a small blower mounted with cleaning sieves. The main blower consisted of four blades and was used to remove chaff from the grain. The 3 mm thick M.S. sheet was used for blower blades. This central shaft of centrifugal blower was powered through belt and pulley. The designed measurement centrifugal fan blowers were shown in Table 2.

### Main frame and transportation unit

It consisted of a main frame and two driving wheels used to mound accessories and transportation respectively. Main frame was fabricated such strong to withstand the load of thresher parts. Main frame was made up of M.S. sheet formed channel.

### Power transmission unit

This system took power through the PTO shaft connected with tractor PTO at one and another end with main shaft of thresher. The accessories installed in this system were fly wheel/balance weight, bearing casing, main multi-grooved pulley, shaft coupling, double groove pulley, feed (tanga) pulley and flat belt pulley. Bearing casings were installed to avoid dust contact and keep smooth movement. The casing was manufactured with cast iron.

The flywheel or balance weight (diameter = 492 mm, 80 kg) fabricated with cast iron was installed at main shaft to absorb inertial force. The main multi-grooved pulley made up of cast iron was installed to connect tractor PTO shaft and rest of the thresher parts. The power was transmitted from a large pulley of PTO input shaft to small, grooved pulley connected to threshing cylinder through double V-belt. The revolution of threshing drum was calculated using the expression.

$$N_2 = \frac{N_1 D_1}{D_2} \text{-----(1)}$$

Where

$N_1$  &  $N_2$  = Number of revolutions of PTO shaft and cylinder shaft (540 and 800 r/min) respectively

$D_1$  &  $D_2$  = Diameter of pullies at PTO and cylinder shaft respectively.

A big feed pulley was used to lower the revolutions of feed shaft required for star wheel shaft (70 r/min). The pully (diameter,

406 mm) was determined using relationship (1). A flat belt pulley (305mm diameter) connected at rear end of main shaft was fabricated with cast iron to operate the thresher with flat belt through a pulley run by PTO of shaft if required. The thresher was tested intensively at three farmer fields (Southern Punjab) during wheat season 2017-18 to evaluate the thresher performance for three wheat varieties Seher 2006 (V1), Faisalabad 2008 (V2) and Lasani 2008 (V3) at

three different harvesting stages (moisture content) of wheat crop; early harvesting stage, mid harvesting stage and late harvesting stage and Feeding rate (FR<sub>1</sub>, FR<sub>2</sub> & FR<sub>3</sub>) on threshing efficiency, grain cleaning efficiency, grain breakage percentage, grain loss in straw, straw chopping efficiency and fuel consumption to observe optimum threshing conditions for each variety. The variable level and their description were presented in Table 3.

**Table 1** Salient features, component specification and materials of wheat thresher

| Feature                                       | Specification   |
|---|---|
| <b>General</b>                                |   |
| Make  | Local made except where different origins are specifically indicated  |
| Type  | Automatic with double blower  |
| Tractor requirement                           | ≥ 50 hp   |
| Power input                                   | PTO shaft driven  |
| <b>Main frame &amp; transportation system</b> |   |
| Length  | 3700 mm   |
| Width   | 1600 mm   |
| Height  | 1900 mm   |
| Weight  | 1400 kg   |
| Main frame                                    | 75 × 75 × 6 mm, 62 × 62 × 6 mm M.S. angle or 4.5 mm M.S. sheet formed channel   |
| Hitch   | 4 mm M.S. sheet formed channel  |
| Number of driven Wheels                       | 2 (6:00-16)   |
| <b>Feeding &amp; threshing system</b>         |   |
| Width   | 1375 mm   |
| Number of cutters/hammers                     | 108   |
| Balance weight                                | 80 kg (2 in Numbers)  |
| Speed   | 800 r/min   |
| Number of feeding stars wheel                 | 8   |
| Threshing capacity (Theoretical)              | 1400-1800 kg/h  |
| Drum cover                                    | 3 mm M.S. sheet   |
| Threshing drum, Rings, Cutter bars, Cutters   | Width 1376 mm, 05 Nos. 50 × 8 mm M.S. steel cast, 08 Nos. 50 × 50 × 6 mm M.S. angle, minimum 100 Nos. 38 × 10 mm M.S. flat with tool tips |
| Concave                                       | 6 × 9 mm rectangular M.S. bar   |
| Feeding hopper/chute                          | 07 Nos. steel cost  |
| Feeder shaft                                  | 47 mm M.S. round, cold drawn  |
| <b>Sieving &amp; cleaning system</b>          |   |
| Number of Blower                              | 2   |
| Speed   | 800rpm  |
| No/Size of sieves holes                       | 2, M.S sheet 1.25 thick round hole, (Upper 7 mm & lower 2.4mm)  |
| Grain/chaff outlet                            | M.S. sheet of 12 gauge  |
| Main blower                                   | 3 mm M.S. sheet   |
| <b>Power transmission system</b>              |   |
| PTO shaft                                     | 47 mm or above M.S. round cold drawn  |
| Balance weight                                | 02 Nos. cast iron (minimum 80 kg each)  |
| Threshing shaft                               | 70 mm M.S. sheet round, cold drawn  |
| Bearings                                      | 02 Nos. 6309  |
| PTO shaft                                     | 02 Nos. 6313  |
| Threshing shaft                               | 02 Nos. 6209  |
| Feeding shaft wheels                          | 04 Nos. 6207/6208   |
| Cam shaft                                     | 02 Nos. 6307/6208, 6215/6212  |

**Table 2** Design calculation of centrifugal fan blower

| Component                | Dimension                 |
|--------------------------|---------------------------|
| Small blower             |                           |
| Blade (L × W)            | (375 × 171.4) mm          |
| Shaft (L × W), Diameter  | (1140 × 377.5) mm, 155 mm |
| Housing                  | Split in two sections     |
| Main blower              |                           |
| Blade (a), (L × W)       | (375 × 262.5) mm          |
| Housing (b)              | (1505 × 262) mm           |
| Outlet size (c), (W × H) | (282 × 282) mm            |

## Independent parameters

### Drum speed and concave clearance

The thresher was operated at designed drum operating speed and concave clearance as 800 rpm and 31 mm respectively (Sudajan et al., 2005). The higher teeth speed that critical speed impact damaged the wheat grain (Xu & Li, 2011).

### Moisture content

Moisture content of wheat crop is essential for good quality wheat threshing. The moisture content of wheat crop majorly influenced threshing performance. The moisture content of wheat crop was calculated by oven dry method (130°C for 19 Hours, ASAE, 2002).

$$GMC = \frac{W_{gw} - W_{gd}}{W_{gw}} \times 100 \quad (2)$$

$$SMC = \frac{W_{sw} - W_{sd}}{W_{sw}} \times 100 \quad (3)$$

Where

GMC, SMC = grain and straw moisture content respectively, % (Wb).

(Wgw, Wgd) and (Wsw, Wsd) = Wet and dry weight of grain and straw respectively, (g)

### Grain straw ratio

Grain straw ratio was measured by separating grain from straw.

$$GSR = \frac{W_g}{W_s} \quad (4)$$

Where

GSR = grain straw ratio

Wg and Ws = weight of grain and straw,

(kg)

### Feeding rate

Feeding rate affects threshing performance of threshing and measured by collecting 15kg, 20kg, and 25kg of wheat crop into the threshing unit for known time as discussed by (Ukatua, 2006).

$$FR = \frac{Q_{mf}}{T} \quad (5)$$

Where

FR = Feeding rate, (kg/h)

Qmf = quantity of crop material, (kg)

T = feed time, (h)

## Dependent parameters

### Threshing efficiency

Threshing efficiency was determined by taking three samples of threshed grains, weight of sample was measured excluding un-threshed grain (Mahmoud et al., 2007).

$$TE = \frac{Q_t}{Q_{nt}} \times 100 \quad (6)$$

Where

TE = threshing efficiency, %

Qt, Qnt = weight of threshed and un-threshed grains, g

### Grain breakage percentage

The grains are required to be in their original form as the broken grains are more liable for the attack of insects or pests. The three samples of threshed grain were taken, and grain breakage was calculated by expression given below (Ukatua, 2006).

$$GBP = \frac{W_b}{W_t} \times 100 \quad (7)$$

Where;

GBP = grain breakage percentage, %

Wb = weight of broken grain, g

Wt = Total weight of sample, g

### Cleaning efficiency

Cleaning efficiency is vital because of value addition with respect to agricultural machinery. Three weights of three samples of threshed grains were measured. The weight was measured again after cleaning the grain samples. The cleaning efficiency was calculated by the equation (Ukatua, 2006).

$$CE = \frac{g}{g+s} \times 100 \quad (8)$$

Where

CE = cleaning efficiency %

g, s = number of grain and foreign matter in sample

### Grain loss in straw

The number of grains were calculated in three samples of straw during wheat threshing and weighted. The expressions used were given below.

$$GLS = \frac{W_{gs}}{FR} \times 100 \quad (9)$$

Where

GLS = grain loss in straw, %

W<sub>gs</sub> = weight of grain in straw, g/min

FR = Feeding rate, kg/min

### Straw chopping efficiency

Straw chopping efficiency of thresher for different wheat varieties were measured. The three samples of variable chaff length measure the length of chaff. The average length was

measured and recorded (Tavakoli et al., 2009).

### Fuel consumption

The economic operation and feasibility of agricultural machinery is based on its fuel consumption. The fuel consumption of wheat thresher and energy consumed were observed for all feed rates of three wheat varieties. The parameters level and their descriptions are given in Table 3.

**Table 3** Variables level and their description

| Wheat varieties                  | Parameters   |
|----------------------------------|--|
| V <sub>1</sub> = Seher 2006      | M <sub>1</sub> = early harvesting stage (Maximum moisture content) |
| V <sub>2</sub> = Faisalabad 2008 | M <sub>2</sub> = mid harvesting stage (Medium moisture content)    |
| V <sub>3</sub> = Lasani 2008     | M <sub>3</sub> = late harvesting stage (low moisture content)      |
|                                  | FR <sub>1</sub> = Low feed rate                                    |
|                                  | FR <sub>2</sub> = Medium feed rate                                 |
|                                  | FR <sub>3</sub> = Maximum feed rate                                |

## Results and Discussion

### Independent parameters

The independent parameters used to evaluate the performance of wheat thresher were wheat varieties, wheat feeding rate into the threshing drum of wheat thresher and moisture content of wheat crop at three harvesting stages as presented in Table 4. The wheat thresher was intensively

tested for Seher 2006 (V<sub>1</sub>), Faisalabad 2008 (V<sub>2</sub>) and Lasani 2008 (V<sub>3</sub>). The wheat feed rates 41, 47 and 52kg/min were determined and the crop moisture content of each wheat variety at three harvesting stages was also measured. Table 3 showed that the maximum wheat crop moisture 22.2% and 17.4% were observed at early harvesting and mid harvesting stages of Seher 2006 (V<sub>1</sub>) while Lasani 2008 (V<sub>3</sub>) gave 11.6% at late harvesting stage. The average wheat crop moisture 21.4%, 16.6% and 11.2% were measured at early harvesting, mid harvesting, and late harvesting stages respectively.

**Table 4** Description and observation of independent parameters

| Independent parameters            | Observation            |                      |                       |
|-----------------------------------|------------------------|----------------------|-----------------------|
| Feeding rate (kg/min)             |                        |                      |                       |
| FR <sub>1</sub>                   |                        | 41                   |                       |
| FR <sub>2</sub>                   |                        | 47                   |                       |
| FR <sub>3</sub>                   |                        | 52                   |                       |
| Moisture content (%)              |                        |                      |                       |
| Wheat varieties                   | Early harvesting stage | Mid harvesting stage | Late harvesting stage |
| Seher 2006 (V <sub>1</sub> )      | 22.2                   | 17.4                 | 11.2                  |
| Faisalabad 2008 (V <sub>2</sub> ) | 20.6                   | 15.9                 | 10.8                  |
| Lasani 2008 (V <sub>3</sub> )     | 21.3                   | 16.4                 | 11.6                  |
| Average moisture contents         | 21.4                   | 16.6                 | 11.2                  |

### Dependent parameters

#### Threshing efficiency

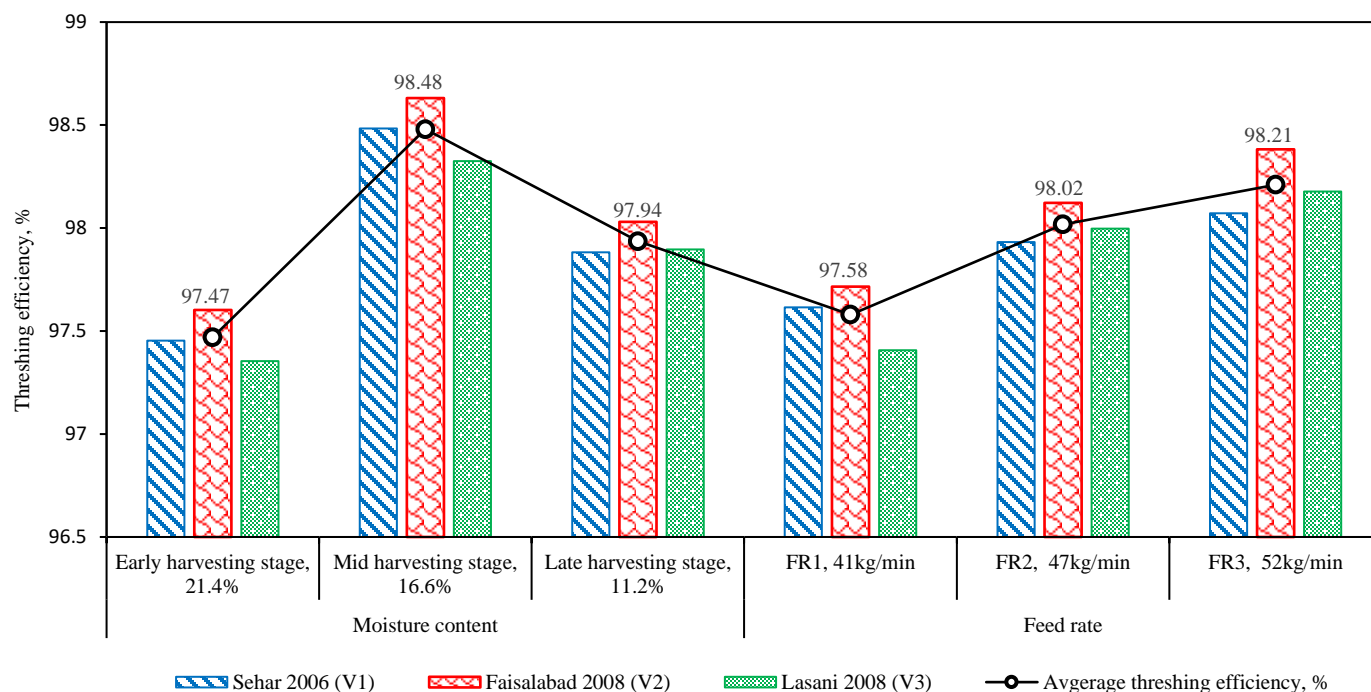
The effect of wheat crop moisture and wheat feed rate into the threshing drum of thresher on threshing efficiency of wheat thresher presented in Fig. 2 indicated that the threshing efficiencies of wheat thresher both for wheat moisture content and wheat feed rate were significantly highest at mid harvesting stage of wheat and feed rate of

52kg/min followed by late harvesting stage and feed rate of 47kg/min while the minimum threshing efficiencies were found at early harvesting stage and feed rate of 41kg/min. Fig. 2 also depicted the analysis of moisture content of wheat crop and threshing performance for three different wheat varieties and all these varieties gave maximum threshing efficiency at mid harvesting stage of crop while lowest at early harvesting stage. The wheat varieties Faisalabad 2008 (V<sub>2</sub>) showed maximum threshing efficiency followed by Seher 2006 (V<sub>1</sub>) while the wheat variety Lasani 2008 (V<sub>3</sub>) gave lowest threshing efficiency

at all harvesting stages of wheat crop. It depicted that the beater gave maximum threshing efficiency in threshing unit for threshing of wheat ears with concave and the detaching grain efficiency with minute damage. Wheat thresher had 97.47%, 98.48% and 97.94% average threshing efficiencies at early harvesting (21.4%), mid harvesting (16.6 %) and late harvesting (11.2%) respectively. The decrease in moisture content from early harvesting stage (21.4%) and increased from late harvesting stage (11.2%) resulted in increased threshing efficiency. The findings are in line with (OAEC, 2007) that the best suited moisture content for wheat thresher is 14-18%. It could be concluded that the brittle nature of grain with decrease in moisture content withstand against impact of beaters fixed at threshing drum.

The result of wheat threshing in response to feeding rate were presented in Fig. 2. It is clear from the figure that the mean threshing of wheat was more with an increase in feeding rate from FR<sub>1</sub>, 41 kg/min to FR<sub>2</sub>, 52 kg/min. Wheat

variety Faisalabad 2008 (V<sub>2</sub>) had significantly maximum threshing efficiency than Seher 2006 (V<sub>1</sub>) and Lasani 2008 (V<sub>3</sub>) at all levels of feeding rates. The wheat variety Faisalabad 2008 (V<sub>2</sub>) had maximum threshing efficiencies than other wheat varieties were 97.72%, 98.12% and 98.38% at feeding rate 41kg/min, 47kg/min, and 52kg/min respectively. The average threshing efficiencies of Seher 2006 (V<sub>1</sub>), Faisalabad 2008 (V<sub>2</sub>) and Lasani 2008 (V<sub>3</sub>) were 97.58%, 98.02% and 98.21% respectively. It was observed that more the feeding rate less were the threshing efficiency and grain breakage, therefore one feeding quantity must be selected for good threshing performance and economically. The wheat thresher produced less grain breakage and maximum threshing efficiency at feeding rate FR<sub>3</sub> (52 kg/min). It would be good to use the thresher at FR<sub>3</sub> (52kg/min) for better threshing efficiency otherwise select medium feed rate FR<sub>2</sub> (47 kg/min). The results are the same as Noor et al. (2020a).

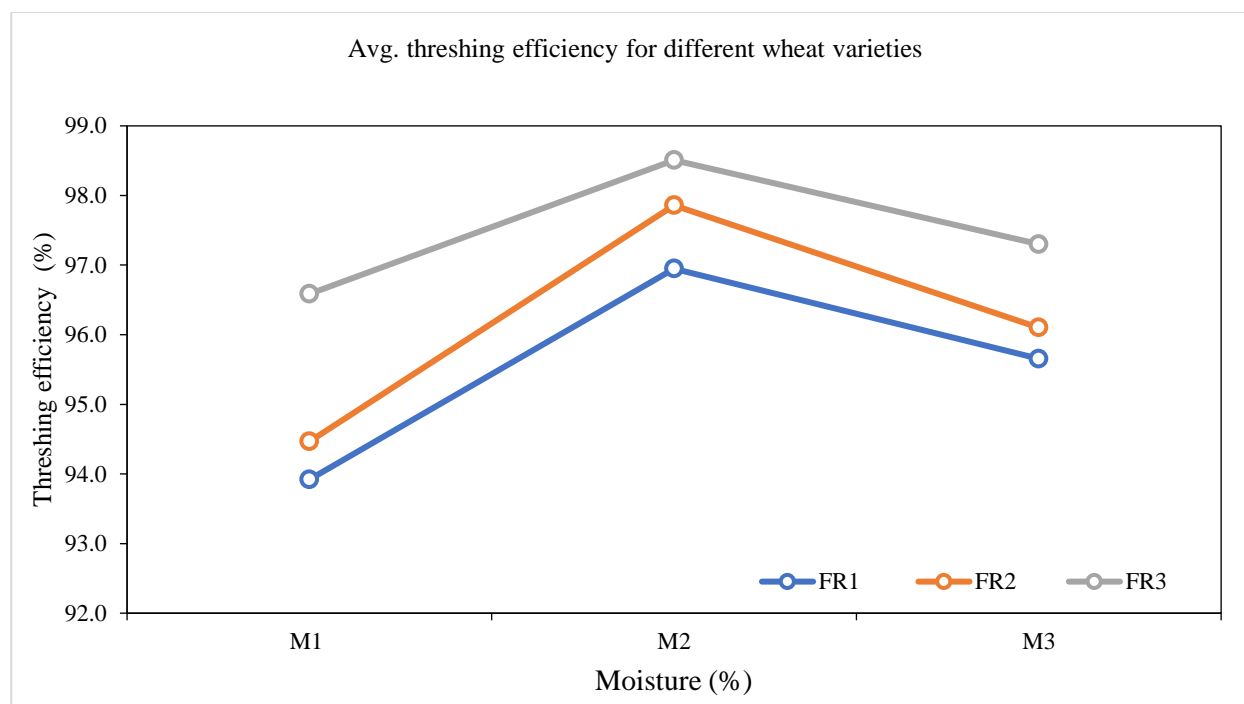


**Fig. 2** Effect of wheat moisture content and feeding rate on threshing efficiency of different wheat varieties

Fig. 3 showed the simultaneous effect of moisture content and feed rate on threshing efficiencies of different wheat varieties. Fig. 3 indicated that threshing showed maximum threshing efficiency at mid harvesting stage of wheat crop followed by late harvesting stage while the threshing efficiency was lowest at early harvesting stage of wheat

crop. The wheat thresher with FR<sub>3</sub> (52 kg/min) produced maximum threshing efficiency at mid harvesting stage (16.6%) than late harvesting (11.2%) and early harvesting (21.4%) respectively. The mean threshing efficiencies of wheat thresher were 97.32%, 98.40% and 97.87%, respectively.





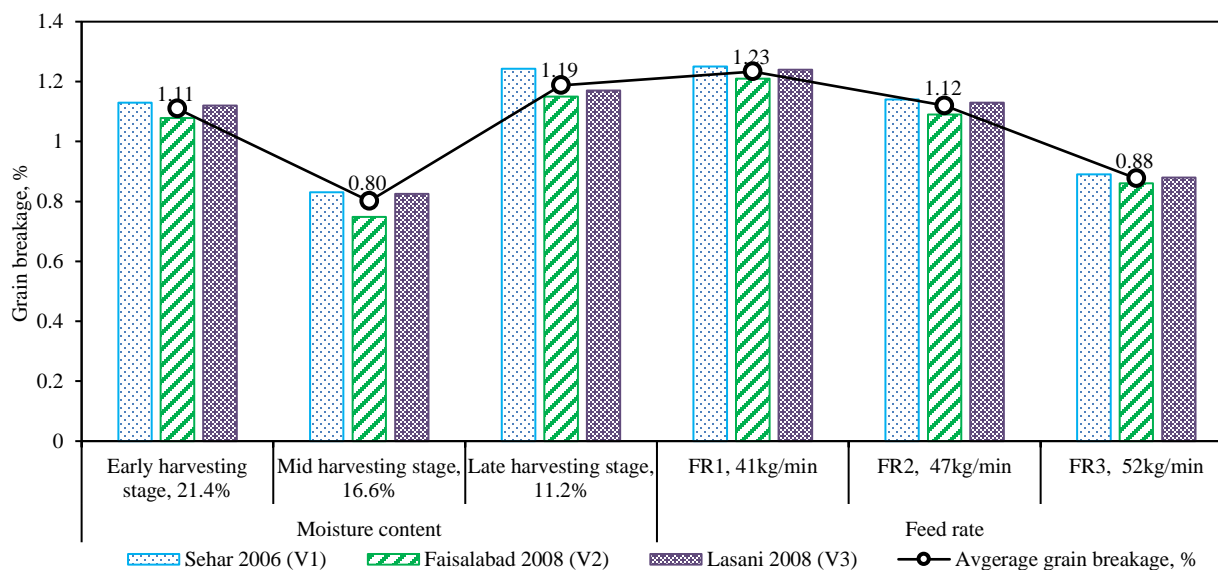
**Fig. 3** Effect of moisture content and feed rate on threshing efficiency of wheat crop

### Grain breakage percent

The grain breakage produced by wheat thresher during the threshing of three different wheat varieties was presented in Fig. 4 indicated that wheat thresher produced the significantly lowest wheat grain breakage at mid harvesting stage of wheat and feed rate of 52 kg/min. The wheat thresher showed maximum grain breakage at late harvesting stage and feeding rate FR<sub>1</sub> (41 kg/min). The average grain breakage over crop moisture and wheat varieties was shown in Fig. 4 that the thresher gave lowest grain breakage at mid harvesting stage of wheat and feed rate of 52 kg/min. The wheat variety Faisalabad 2008 (V<sub>2</sub>) had significantly lowest susceptibility to grain breakage than other two varieties Seher 2006 (V<sub>1</sub>) and Lasani 2006 (V<sub>3</sub>). In Fig. 6, it is clearly reflected that Seher 2006 (V<sub>1</sub>) had more grain breakage than other varieties at all moisture content levels. It could be concluded that the wheat variety Faisalabad 2008 (V<sub>2</sub>) had optimum resistance against threshing impact of beater than Lasani 2006 (V<sub>3</sub>) & Seher 2006 (V<sub>1</sub>) respectively. The wheat varieties Seher 2006 (V<sub>1</sub>), Faisalabad 2008 (V<sub>2</sub>) and

Lasani 2006 (V<sub>3</sub>) had 1.24%, 1.15% and 1.17% grain breakage at late harvesting stage & 1.13%, 1.07% and 1.12% at early harvesting stage while lowest grain breakage 0.83%, 0.74% and 0.82% at mid harvesting stage. Fig. 4 also showed the average breakage was found maximum (1.19%) at the late harvesting stage as compared to mid harvesting stage (0.8%) and early harvesting stage (1.11%). This showed that the grain breakage was directly affected by grain moisture. These results are similar as reported by (Arnold, 1964; Noor et al., 2020b) who reported the grain breakage increases as the wheat crop moisture is reduced from 14% and increased from 18%. The effect of feed rate and wheat varieties on grain breakage were presented in Fig. 6 indicated that grain breakage was found lowest at feeding rate FR<sub>3</sub> 52 kg/min and maximum grain breakage at FR<sub>1</sub> 41 kg/min. the wheat variety Faisalabad 2008 (V<sub>2</sub>) had significantly lower grain damage (0.89%, 0.86% and 0.88%) than other two wheat varieties at all selected feeding rates. The average grain breakage of thresher was lowest (0.88%) at feed rate of FR<sub>3</sub> 52 kg/min than 1.12 and 1.23 at FR<sub>2</sub> 47kg/min and FR<sub>1</sub> 41kg/min respectively. The results were in line with as reported by Noor et al. (2019).

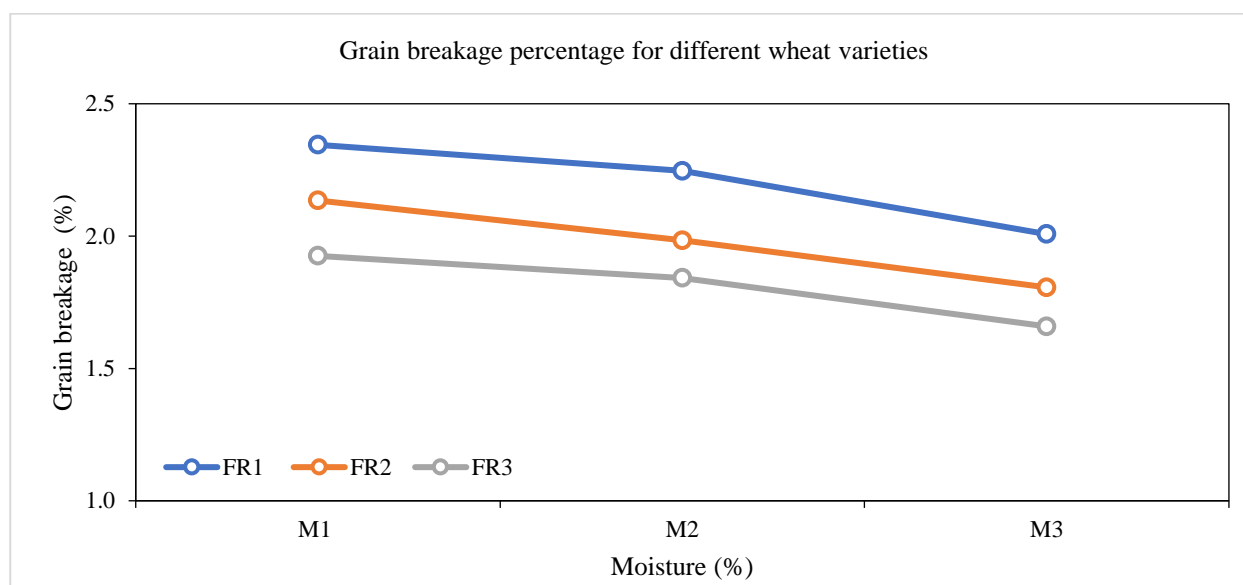




**Fig. 4** Effect of wheat moisture content and feeding rate on threshing of different wheat varieties

Fig. 5 showed the simultaneous effect of moisture content and feed rate on grain breakage of different wheat varieties. Fig. 5 indicated that thresher showed least grain breakage at mid harvesting stage of wheat crop followed by early harvesting stage while the grain breakage was maximum at late harvesting stage of wheat crop. The wheat thresher with

FR<sub>3</sub> (52 kg/min) produced maximum average grain breakage at late harvesting stage (1.19%) than early harvesting stage (1.08%) while the least were at mid harvesting stage (0.98%). The grain breakage in thresher with feed rate FR<sub>3</sub> 52 kg/min had 0.92%, 0.75% and 0.99% at early harvesting, mid harvesting, and late harvesting stages, respectively.



**Fig. 5** Effect of wheat moisture content and feeding rate on grain breakage during threshing

### Cleaning efficiency

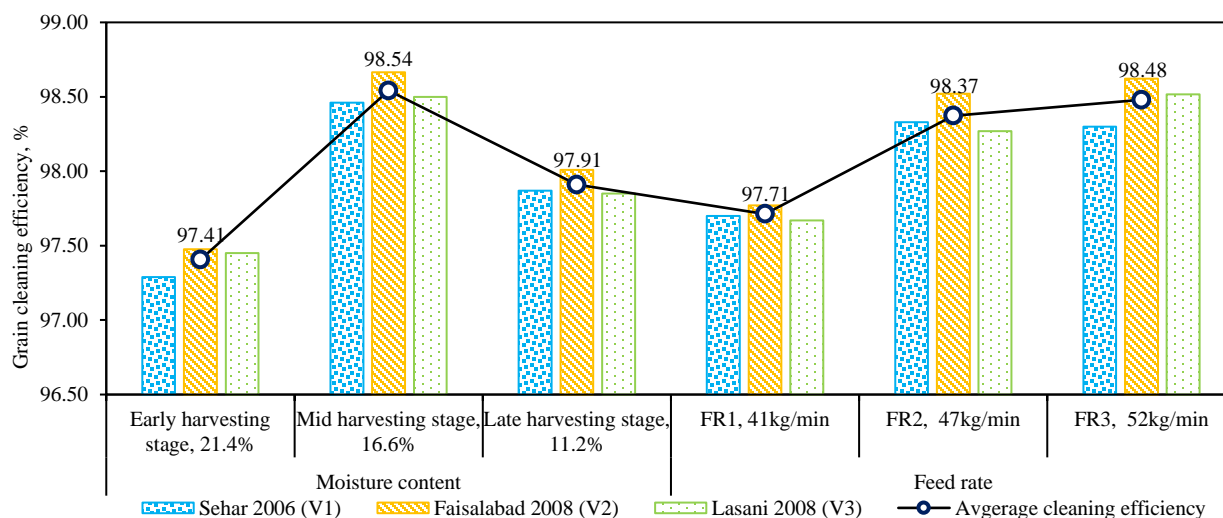
The analysis of grain cleaning efficiency of newly designed and developed wheat thresher presented in Fig. 6 indicated that the wheat thresher produced the significantly highest cleaning efficiency at mid harvesting stage of wheat and

feed rate of 52 kg/min. The wheat thresher showed the lowest cleaning efficiency at the initial harvesting stage and feeding rate FR<sub>1</sub> (41 kg/min). Fig. 6 depicted the correlation between crop moisture and cleaning efficiency for different wheat varieties. The average cleaning efficiencies were observed maximum (98.54%) when threshed wheat crop at mid

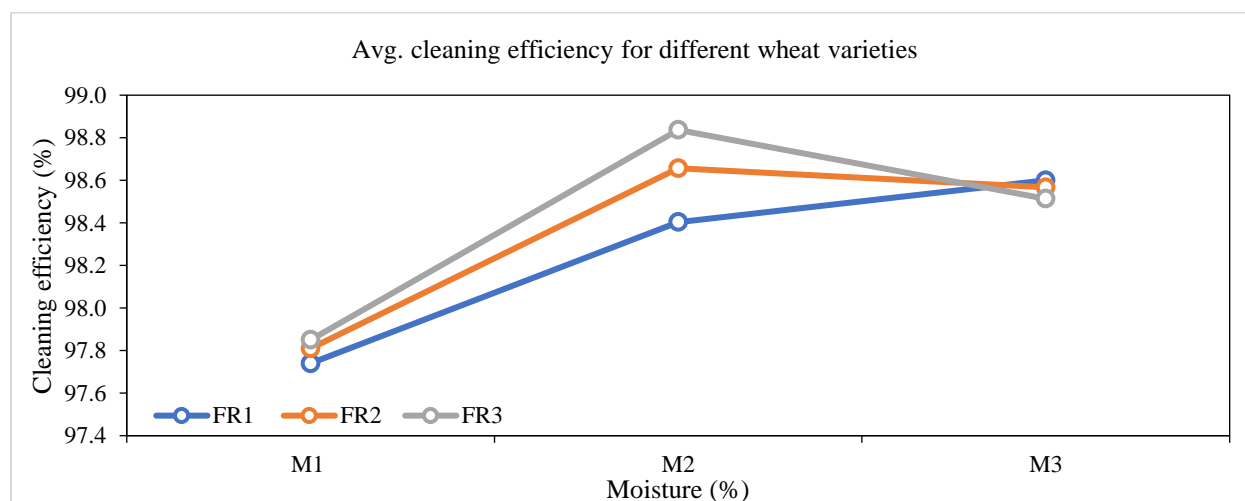
harvesting stage (16.6%) than (97.91%) at late harvesting stage (11.2%) while the thresher operated at early harvesting stage (21.4%) of wheat crop gave lowest (97.41%) cleaning efficiency. This could be evaluated that more threshing efficiency better would be the cleaning efficiency. The wheat variety Faisalabad 2008 ( $V_2$ ) had maximum cleaning efficiency 97.48%, 98.67% and 98.01% followed by Lasani 2008 ( $V_3$ ) had cleaning efficiency 97.45%, 98.50% and 97.85% while the Seher 2006 ( $V_1$ ) had lowest cleaning efficiency 97.29%, 98.46% and 97.87% at moisture content (21.4%), (16.6%) and (11.2%) respectively. The static and dynamic balance was considered during the design and development of the blowers. It could be predicted that at early harvesting stage (21.4%) the weight of chopped straw and damaged grain was more separated from clean grain than that at mid harvesting stage (16.6%). It agreed with the discussed above about even threshing efficiency measured for developed wheat thresher with beater of high carbon steel. The effect of feeding rate on grain cleaning efficiency for wheat varieties was presented in Fig. 6 which showed

that grain cleaning was significantly better for more feeding rate from  $FR_1$ , 41kg/min to  $FR_3$ , 52 kg/min. The average cleaning efficiency at  $FR_1$  41 kg/min,  $FR_2$  47 kg/min and  $FR_3$  52kg/min were found 97.71%, 98.37% and 98.48%. The trend of cleaning efficiency was same as threshing efficiency discussed above. It would have been due to the more straw chopping at less feed rate. The wheat variety Faisalabad 2008 ( $V_2$ ) showed greater cleaning efficiency among all wheat varieties at all feeding rates.

Fig. 7 indicated that thresher showed highest grain cleaning efficiency at mid harvesting stage of wheat crop followed by late harvesting stage while the grain cleaning efficiency was minimum at early harvesting stage of wheat crop. The wheat thresher with  $FR_3$  (52 kg/min) produced maximum average grain cleaning efficiency at mid harvesting stage (98.47%) than late harvesting stage (97.99%) while the least was at early harvesting stage (97.73%). The grain cleaning efficiency in thresher with feed rate  $FR_3$  52 kg/min had 98.20%, 98.93% and 98.57% at early harvesting, mid harvesting, and late harvesting stages respectively.



**Fig. 6** Effect of wheat moisture content and feeding rate on grain cleaning efficiency of different wheat varieties



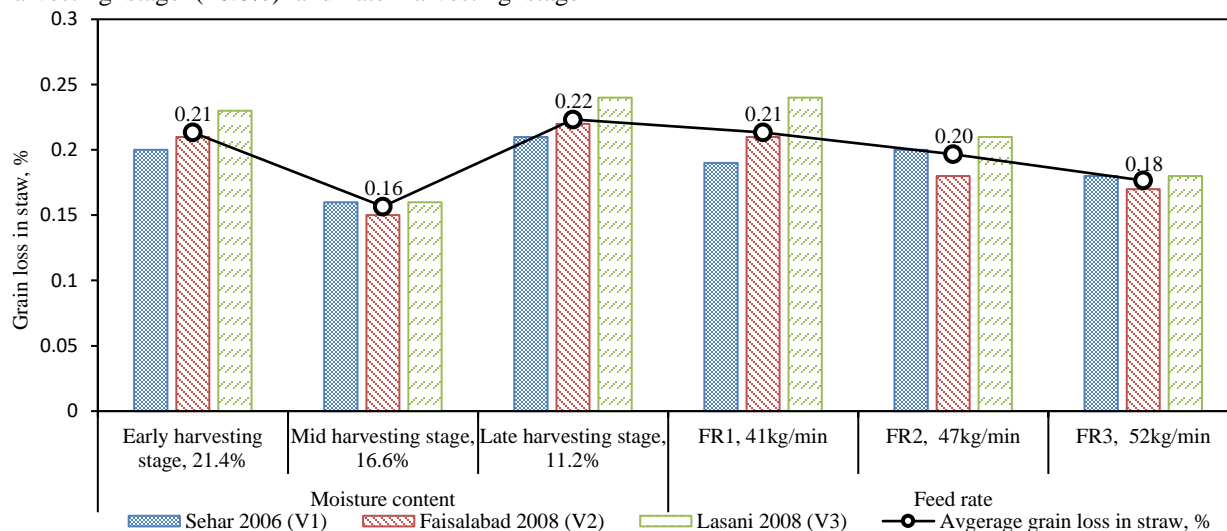
**Fig. 7** Effect of wheat moisture content and feeding rate on grain cleaning efficiency

### Grain loss in straw

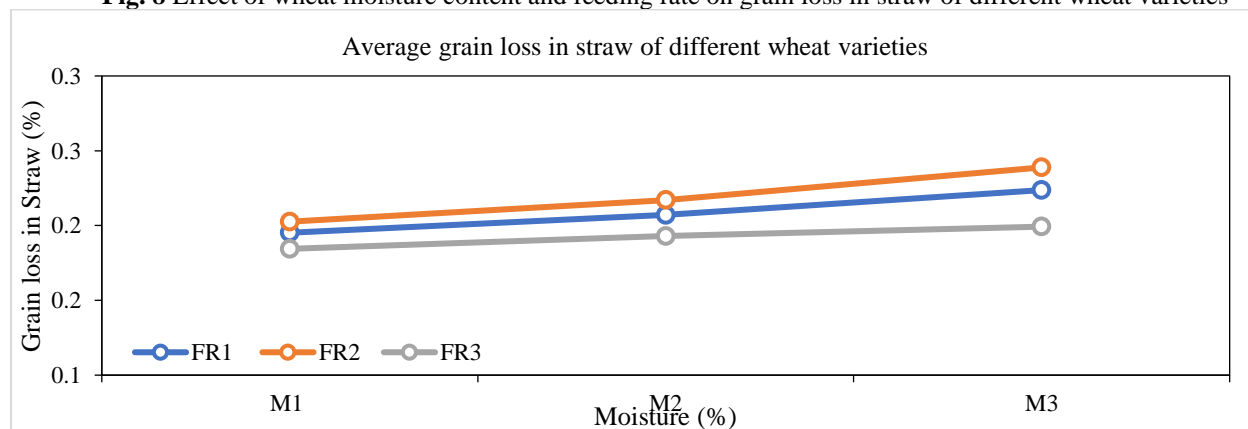
Fig. 8 depicted the analysis carried out for crop moisture content and feeding rate on grain loss in straw by wheat thresher. Fig. 8 showed that the wheat thresher produced the significantly lowest grain loss in straw at mid harvesting stage of wheat and feed rate of 52 kg/min. The wheat thresher showed maximum loss of wheat grain in straw at late harvesting stage and feeding rate FR<sub>1</sub> (41 kg/min). Fig. 8 also depicted the effect of wheat varieties and moisture content on grain loss in straw, the mean grain loss in straw over wheat varieties was significantly low (0.16%) of thresher threshed wheat crop at mid harvesting stage (16.6%) than (0.21%) at early harvesting stage (21.4%) while the thresher operated at late harvesting stage (11.2%) of wheat crop gave highest (0.22%) grain loss in straw. This could be evaluated that more the threshing and cleaning efficiency less would be the grain loss in straw. The wheat variety Lasani 2008 (V<sub>3</sub>) had maximum loss of grain in grain 0.23%, 0.16% and 0.24% followed by Seher 2006 (V<sub>1</sub>) had grain loss in straw 0.20%, 0.16% and 0.21% while the Faisalabad 2008 (V<sub>2</sub>) had lowest loss of grain in straw 0.21%, 0.15% and 0.22% at early harvesting stage (21.4%), mid harvesting stage (16.6%) and late harvesting stage

(11.2%) respectively. It could be predicted that at mid harvesting stage (16.6%) the threshing efficiency was more, grain damaged were less than that at other harvesting stages. The effect of feeding rate and wheat varieties on grain loss in straw of wheat thresher revealed that the higher was the feeding rate from FR<sub>1</sub> 41 kg/min to FR<sub>3</sub> 52kg/min less grain lost in straw. The average grain loss in straw at FR<sub>1</sub> 41kg/min, FR<sub>2</sub> 47 kg/min and FR<sub>3</sub> 52kg/min were found 0.21%, 0.20% and 0.18%. The trend of the grain loss in straw was same as grain breakage discussed above. The wheat variety Faisalabad 2008 (V<sub>2</sub>) showed less grain loss in straw (0.18% and 0.17%) at feed rates FR<sub>2</sub> 47 kg/min to FR<sub>3</sub> 52 kg/min respectively while at feeding rate FR<sub>1</sub> 41kg/min, the wheat variety Seher 2006 (V<sub>1</sub>) showed lowest (0.19%) grain loss in straw.

Fig. 9 indicated that thresher showed the lowest grain loss in straw at mid harvesting stage of wheat crop than early harvesting stage and late harvesting stage of wheat crop. The wheat thresher with FR<sub>2</sub> (47kg/min) showed the lowest average grain loss in straw at mid harvesting stage (0.17%) than early harvesting stage (0.20%) and at late harvesting stage (0.22%). The grain loss in straw in thresher with feed rate FR<sub>2</sub> 47 kg/min had 0.19%, 0.16% and 0.21% at early harvesting, mid harvesting, and late harvesting stages, respectively.



**Fig. 8** Effect of wheat moisture content and feeding rate on grain loss in straw of different wheat varieties



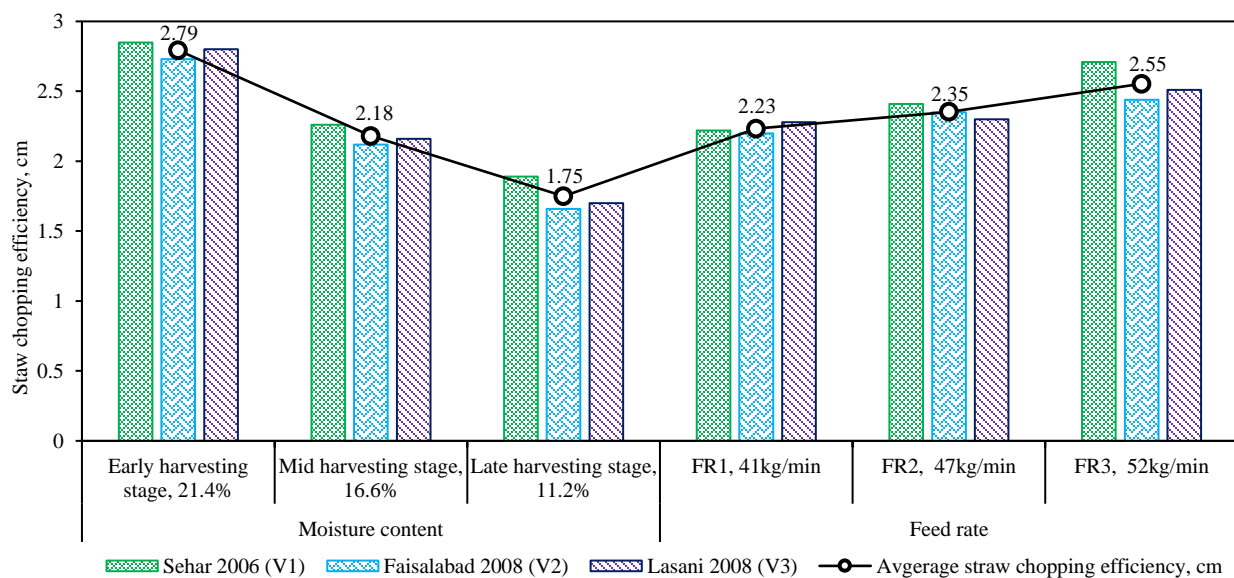
**Fig. 9** Effect of wheat moisture content and feeding rate on grain loss in straw for wheat threshing

### Straw chopping efficiency

Fig. 10 showed the results obtained for straw chopping efficiency of wheat thresher at different moisture levels. It is indicated that the wheat thresher gave the significantly highest straw chopping efficiency at early harvesting stage (21.4%) of wheat and third wheat feeding rate of 52 kg/min into the threshing drum of thresher. The wheat thresher showed the lowest straw chopping efficiency at late harvesting stage (11.2%) and feeding rate FR<sub>1</sub> (41 kg/min). Fig. 10 depicted the effect of wheat varieties and moisture content on straw chopping efficiency, the mean straw chopping efficiency over wheat varieties was significantly greater (2.79 cm) at early harvesting stage (21.4%) than (2.18 cm) at mid harvesting stage (16.6%) and (1.75 cm) late harvesting stage (11.2%) of wheat crop. This could be evaluated that more uniform and smooth threshing efficiency, better would be the straw chopping efficiency and straw size produced at mid harvesting stage were best suited for straw storage and for feed. There was no significant difference of straw chopping of three different wheat varieties, the wheat variety Faisalabad 2008 (V<sub>2</sub>) had lower size of chopped straw 2.73 cm, 2.12 cm and 1.66 cm than that of other wheat varieties at moisture content (21.4%), (16.6%) and (11.2%) respectively. It could be predicted that at early harvesting stage (21.4%) the bigger

chopped straw size was due to high moisture content in the wheat straw. The effect of feeding rate and wheat varieties on straw chopping efficiency of wheat thresher presented in Fig. 10 showed that the increment in feeding rates from 41 kg/min to 52 kg/min increased straw chopping efficiency significantly. The average straw chopping efficiency at FR<sub>1</sub> 41 kg/min, FR<sub>2</sub> 47 kg/min and FR<sub>3</sub> 52 kg/min were found 2.23 cm, 2.35 cm and 2.55 cm. The trend of straw chopping efficiency was same as threshing efficiency and cleaning efficiency discussed above. It would have been due to the more straw chopping at less feed rate. The wheat variety Faisalabad 2008 (V<sub>2</sub>) showed lower straw chopping efficiency (2.22 cm) at FR<sub>1</sub> 41 kg/min and (2.44 cm) at FR<sub>3</sub> 52 kg/min while wheat variety Lasani 2008 (V<sub>3</sub>) gave lowest (2.30 cm) chopped straw size at feeding rates FR<sub>2</sub> 47 kg/min.

The effect of wheat moisture and feeding rate on the threshing drum of wheat thresher was presented in Fig. 11. It is indicated that the highest straw chopping efficiency of all feeding rates were observed at early harvesting stage of wheat crop followed by mid harvesting stage while the straw chopping efficiency was minimum at late harvesting stage of wheat crop. The wheat thresher with FR<sub>1</sub> (41 kg/min) produced minimum straw chopping efficiency at all harvesting stages of wheat crop. The mean straw chopping efficiency at early harvesting stage (2.80 cm), late harvesting stage (2.28 cm) and least was at early harvesting stage (1.93 cm), respectively.



**Fig. 10** Effect of wheat moisture content and feeding rate on straw chopping efficiency of different wheat varieties

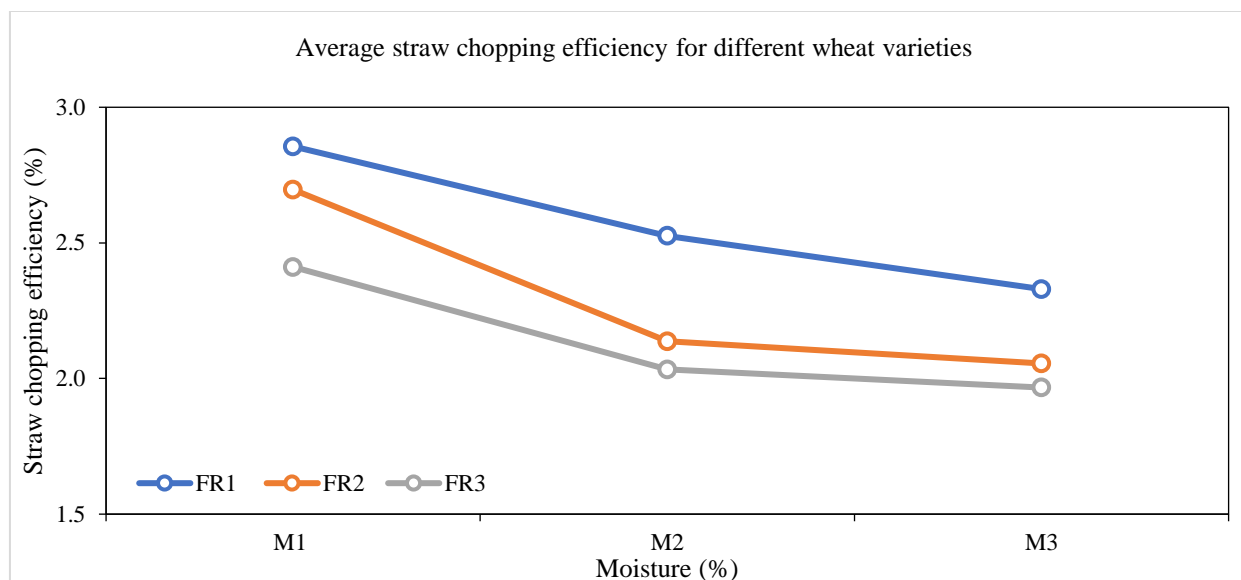


Fig. 11

Effect of wheat moisture content and feeding rate on straw chopping efficiency

### Fuel consumption

Table 5 depicted the results obtained for fuel consumed and energy utilized for the threshing of wheat at three different feeding rates. Table indicated that feeding rate FR<sub>1</sub> 41 kg/min had lowest fuel consumption 6.41 L/h for Seher 2006 (V<sub>1</sub>) and FR<sub>3</sub> 52 kg/min had maximum fuel consumption 6.71 L/h for wheat variety Lasani 2008 (V<sub>3</sub>). The mean fuel consumed by the wheat thresher were 6.45 L/h, 6.56 L/h and 6.68 L/h at feeding rates FR<sub>1</sub> 41 kg/min,

FR<sub>2</sub> 47 kg/min and FR<sub>3</sub> 52 kg/min and wheat varieties Seher 2006 (V<sub>1</sub>), Faisalabad 2008 (V<sub>2</sub>) and Lasani 2008 (V<sub>3</sub>) had fuel consumption 6.54 L/h, 6.88 L/h and 6.60 L/h respectively. This was true the more feed material would be the fuel consumption. The energy utilized against the fuel consumed was calculated @ 1-liter diesel = (0.893 kg) (46 MJ/kg) (0.28 kW/MJ) = 11.5 kWh. The thresher operated at FR<sub>3</sub> 52 kg/min showed maximum energy utilization 80.43 kWh while the wheat variety Faisalabad 2008 (V<sub>2</sub>) had maximum energy utilization 78.91 kWh.

**Table 5** Effect of feed rate on fuel consumption and energy of wheat thresher

| Feed rate                   | Fuel consumption (L/h)       |                                   |                               |       | Energy (kWh)                 |                                   |                               |       |
|-----------------------------|------------------------------|-----------------------------------|-------------------------------|-------|------------------------------|-----------------------------------|-------------------------------|-------|
|                             | Seher 2006 (V <sub>1</sub> ) | Faisalabad 2008 (V <sub>2</sub> ) | Lasani 2008 (V <sub>3</sub> ) | Mean  | Seher 2006 (V <sub>1</sub> ) | Faisalabad 2008 (V <sub>2</sub> ) | Lasani 2008 (V <sub>3</sub> ) | Mean  |
| FR <sub>1</sub> , 41 kg/min | 6.41                         | 6.44                              | 6.49                          | 6.45  | 73.48                        | 73.82                             | 74.40                         | 73.90 |
| FR <sub>2</sub> , 47 kg/min | 6.55                         | 6.53                              | 6.60                          | 6.56  | 75.08                        | 74.85                             | 75.66                         | 75.20 |
| FR <sub>3</sub> , 52 kg/min | 6.66                         | 6.68                              | 6.71                          | 6.68  | 76.34                        | 76.57                             | 76.92                         | 80.43 |
| Mean                        | 6.54                         | 6.88                              | 6.60                          | 6.562 | 74.97                        | 78.91                             | 75.66                         | 76.51 |

### Conclusion

In conservation agriculture system, it was required to optimize the threshing performance of wheat thresher operated at variable crop moisture & feed rate and to suggest suitable working parameters for threshing. Analysis of dependent parameters observed during the field testing indicated that the performance of wheat thresher was maximum for variety Faisalabad-2008 (V<sub>2</sub>) than Sehar-2006 (V<sub>1</sub>) and Lasani-2008 (V<sub>3</sub>). The maximum mean threshing efficiency and grain cleaning efficiency of wheat thresher were reached up to 98.83% and 98.93%,

respectively, when threshing was done at mid harvesting stage (16.6%) and feed rate, 52 kg/min. The grain breakage percentage and quantity of grain lost in wheat straw were found at least 0.75% and 0.16%, respectively at feed rate, 47 kg/min and mid harvesting stage (16.6%). The wheat thresher chopped straw (2.28cm) accurate and uniform at moisture content 16.6% (mid harvesting stage) while the straw chopping was non-uniform and irregular at late harvesting stage of wheat crop (1.93cm). The maximum fuel consumption and energy utilized were observed at 6.71 L/h and 76.57 kWh respectively for wheat variety Lasani-2008 (V<sub>3</sub>) at feeding rate FR<sub>3</sub>, 52 kg/min. This study suggested suitable wheat crop moisture and feed rate for

maximizing threshing performance in conservation agriculture system. Further studies will be conducted that aim to reach the highest threshing efficiency and minimum grain losses selecting appropriate crop moisture content and feeding rate.

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